Evaluation of Transmission Reliability Margin in Automatic Transmission Capacity Calculation

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Abstract: **The paper deals with an approach to the evaluation of Transmission Reliability Margin (TRM) in automatic cross-border transmission capacity assessment of electric power interconnections. It is based on advanced methodology for steady-state security analyses. The practical application of developed approach is made on example of transmission capacity calculation in condition of Second UCTE synchronous zone.**

Keywords - **Cross-border, Transmission Capacity, Automatic Mode, Transmission Reliability Margin, Open Electricity Market**

I. Introduction

An important issue in modern EPS's (Electric Power Systems) is to provide the necessary level of operational security. In recent years, the increased practical interest to this issue has been shown, and corresponding new challenges appeared, mainly due to increased loading of EPS's, combined with a process of liberalization in electric power market and restructuring of the power utilities. Open access power systems need accurate transmission capacities evaluation to guarantee secure operation for all transactions.

Also, the processes above mentioned are very important and topical for all countries in Southeast Europe, as well as for Serbia and Montenegro and its power industry, according to the following facts:

- *Reconnection the Second UCTE synchronous zone with the main part of the UCTE grid*

The Second UCTE synchronous zone was disconnected from the main UCTE grid since 1992, due to war consequences in former SFR Yugoslavia. Since then, there are only periodical island operations between the parts of these zones. The present Second UCTE synchronous zone is consisted of the networks of Albania (AL), Bosnia-Herzegovina (eastern part, RS), Bulgaria (BG), FYR Macedonia (MK), Greece (GR), Romania (RO), Serbia and Montenegro (SCG).The reconnection of the Second zone with the main UCTE grid is successfully made in 10 October 2004.

- *Establishment of Regional Electricity Market*

According to the Memorandum of Understanding [1], all the countries from South-east European region agreed upon the constitution of a competitive Regional Electricity Market (REM) in Southeast Europe. The proposed time period for creation of regional electricity market is last up to year 2006.

The basic objective of this paper is to present an approach to the evaluation of Transmission Reliability Margin (TRM) in automatic cross-border transmission capacity assessment (NTC-Net Transfer Capacity) of interconnections. It is based on advanced methodology for NTC calculation, using all its favourable properties, respecting the latest definitions [2], criterions, standards and practice [3] of European Transmission System Operators (ETSO). The relevant theoretical and practical aspects of this advanced methodology are given in [4, 5, 6, and 7].

The most complex and delicate part of NTC calculation is the evaluation of TRM, which is a security margin that copes with uncertainties on the computed TTC (Total Transfer Capacity) values [2, 3, and 8].

Those uncertainties may arise from: unintended deviation of physical flows due to the load-frequency control, emergency exchange caused by the unexpected unbalanced situations (big injection losses) in real time and inaccuracies in data and calculation models and/or method. This comprehensive set of possible uncertainties explains the existence of many different approaches for the solving of this problem in practice [8, 9, and 10].

The value of TRM can only be estimated, because it should consider all uncertainties of system operation. The value of TRM in majority of EPS is estimated, according the statistical analysis of past data (per instant, statistical study of individual tie line "errors", calculation of standard deviation of tie-line power e.t.c).

Next, in practice, the part of TRM, which corresponds to the inaccuracies in data and calculation models and/or method isn't bigger than 5% of computed TTC value. Also, in practice of ETSO, a reasonable value of TRM usually could be found by assuming an unpredictable power flow mismatch on each interconnecting lines (e.g. 100 MW), multiplied with the square root of its number ($\sqrt{l}$), i.e. TRM [MW] = $100\sqrt{l}$.

This paper deals with the possible way to the evaluation of TRM, respecting the facts that the above mentioned methodology for NTC calculation strictly evaluates the transmission effects of primary frequency and load-frequency controls, i.e. the significant "part" of TRM are included (except the part that takes into accounts the uncertainties on system conditions and the precision data in load-flow models).

This approach is based on two types of NTC calculation. First, the calculation of NTC is make for elements (lines and transformers) outage type of disturbances, and second, for generators outage type of disturbances. According to the automatic mode of NTC calculation, this approach enables very fast and efficient calculation of TTC, for those two types of disturbances. After that, it is possible to make a good estimation for TRM.

The first practical experiences in the application of this approach have been gained on an example of the synchronous

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parallel operation of the EPSs in the Second UCTE synchronous zone.

II. Methodological Aspects of Automatic Cross-Border Transmission Capacity Evaluation

This advanced methodology for automatic cross-border transmission capacity assessment is consisted in the following relevant parts, which differ to the usual approaches:

- Two procedures for initialisation of steady-state security analyses, i.e. the procedure for solving the initial load-flow problems, which precede these analyses [5];
- These procedures are fully consistent with the specially developed method for the following steady-state security analyses [4, 5]. Such characteristic of these procedures enables the unification of corresponding computer program, autonomy and uniformity of steady-state security analysis, as well as their successive realization, which have practical importance;
- The limits of generator reactive power are not constant, a priori defined quantities, but rather corresponding functions of relevant generator parameters and state variables [4]. Also, during the NTC calculation, the generator voltage reference is to be changed according to the corresponding change of generator active power;
- Procedure for fast contingency selection, which is based on results from the single iteration of specially developed fast decoupled load-flow solution method, in which the power system frequency is relevant variable [6];
- Procedure for forming the unified external network equivalents, with adaptive buffer system selection, consistently respecting the effects of primary voltage and frequency control of neighbouring power systems [11];
- Simple method for the accurate assessment of dynamic variation of power system frequency, during the operation of its primary control, as well as the quasi-stationary value of its frequency [12];
- Generalized injected models of transformer, which enables a simple presentation of both energy transformers with or without angle regulation as well as static phase shifting transformers (so-called series FACTS power flow controllers [13];
- Generalized model of generator participation in NTC calculation, which enables the selection of the most convenient ones regarding the real operational practice in new condition of liberalized electricity market [14]. The generation increase/decrease has to be performed proportionally, according to actual spinning reserve.
- Forming the practical and realistic security indices for selection of potentially critical disturbances, according to the real power performances and to the control and protection devices characteristics [6];
- For potentially critical contingency, the continuation of iterative procedure for solving the load-flow problem is performed (full contingency analysis), based on specially developed fast-decoupled method [4].
- The proposed methodology strictly evaluates the transmission effects of primary frequency and load-frequency controls, i.e. the significant "part" of TRM are included (except the part that takes into accounts the uncertainties on system conditions and the precision data in load-flow models).
- This method enables successive solution of the load-flow problem for a set of characteristic post-dynamic quasi-stationary states: states resulting from primary voltage and frequency control, states after the action of automatic secondary control of frequency and tie-line power and states after corresponding possible dispatch activities, if necessary (corrective control) [4].

III. Concept of Automatic Cross-Border Transmission Capacity Evaluation

Fig. 1 [7] presents the global concept of the proposed methodology (computer program STATIC developed in Nikola Tesla Institute) for automatic cross-border transfer capability calculation, using flow diagrams of the basic functions.

This methodology uses a unified data base (block 1), as a segment of the complex database necessary for the operational planning of EPS. For this purpose the UCTE data exchange format is used [15].

If the first option of application is selected (identification and verification of initial steady-state, with bad data processing), only load-flow solution in initial (base) steady-state is performed (block 2).

In the case of second option, after calculation the initial load-flow, the security assessment for this state is made (block 3). This assessment is made respecting the N-1 criterion (per example: outage of single lines 400, 220 and 110 kV, transformers 400/220 kV, 400/110 kV and generators) and N-2 criterion, in case of double circuit.

After the inauguration of initial steady-state that satisfied the security constraints, the automatic cross-border transmission capacity assessment is made. In order to determine the cross-border transmission limit between two neighbouring countries or zones, cross-border exchanges are gradually increased while maintaining the loads in the whole system unchanged until security limits are reached.

Starting from the common base case exchanges, the additional exchange is performed through an increase of generation on the exporting side and an equivalent decrease of generation on the importing side in automatic mode (in step of e.g. 50 MW). This generation shift is to be made stepwise until a network constraint is violated. The security assessment is also made respecting the N-1 security criterion (and N-2, in case of double circuit).

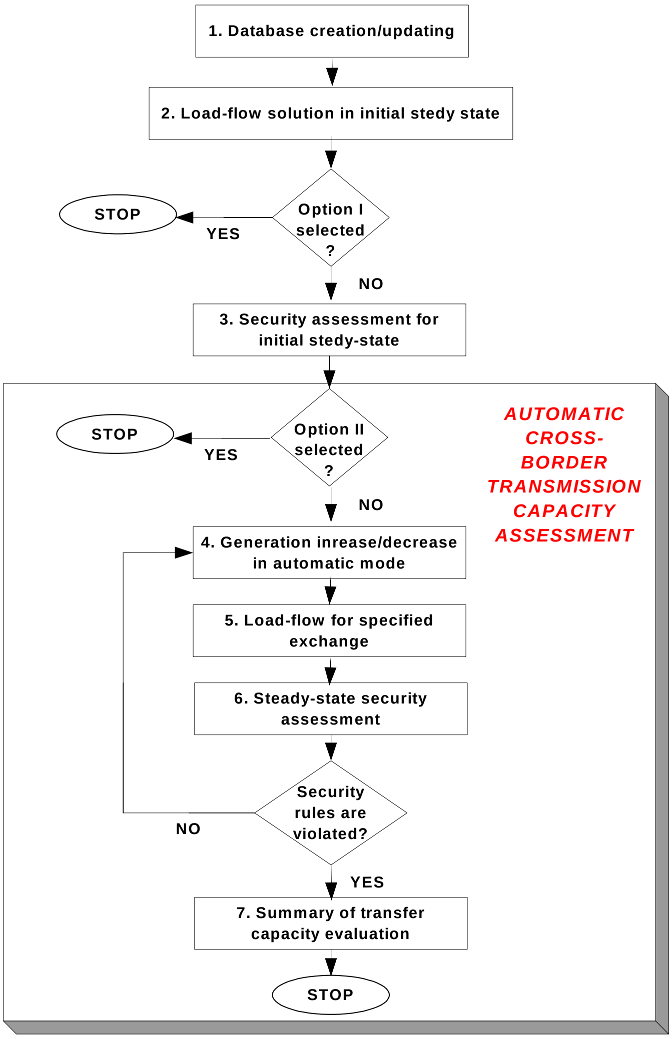

Fig. 1. Flow diagram of automatic cross-border transmission capacity assessment

The procedures, marked in following blocks 4 (generator increase/decrease in automatic mode, proportional to the actual spinning reserve), 5 (load-flow solution for specified exchange in step of 50 MW) and 6 (steady-state security assessment) are stopped, when predefined security rules are violated.

Finally, block 7 gives the summary of transfer capability evaluation. The output results are: TTC, TRM, NTC, Notified Transmission Flow (NTF) and Total Transfer Flow (TTF).

IV. Practical Application

The first practical experiences in the application of the developed approach to the evaluation of TRM have been gained on an example of the present state of the Second UCTE synchronous zone. Fig. 2 [7] shows the block diagram of examined interconnection with the active and reactive power flows (MW/Mvar) over the interconnecting lines in two cases: 1) without any exchange programs between the EPS's (except the exchange between Serbia and Montenegro and part of Republic Spike) and 2) when Romania exports 300 MW to Serbia and Montenegro (values given in parentheses).

Thus, in the first case, the BCE (Base Case Exchange) between the EPS's in interconnection considered (except the above mentioned exchange between SCG and RS) does not exist ("zero" exchange program). In these conditions, the physical power flows on interconnecting lines presented are so-called parallel (or ring) flows, i.e. the physical flow NTF (Notified Transmission Flow) only consists of parallel flows. In this state and also during the security assessment, the relevant network constraints (voltage and current limits) are not violated.

In second case (RO exports 300 MW to SCG), the power flow on interconnecting line Đerdap (SCG) – P. De Fier (RO) changes the direction, and this physical flow of 9 MW (now, in direction RO→ SCG) is in reality the NTF (which is now, in amount of along parallel power flows, results from above mentioned exchange 300 MW). Also, in this state the predefined security rules are satisfied.

This state of interconnection considered (with $BCE^{RO \to SCG} = 300$ MW and $NTF^{RO \to SCG} = 9$ MW) has been the starting point for automatic cross-border transmission capacity calculation, according the flow diagrams (blocks 4, 5, 6 and 7), given in Fig. 1. From many results that were obtained, the case of power exchanges between Romania (exports) and Serbia and Montenegro (imports) has been chosen as a good illustration.

For outage element type of disturbances (all elements, which are loaded more then 40% of own thermal limit are included), the procedure for automatic cross-border transmission capacity assessment is stopped when the total exchange RO → SCG was 750 MW. In this case, the critical outage was the outage of transformer 400/231 kV, 400 MVA in P. De Fier in Romania, and the critical element was the line 220 kV Paroseni-Baro Mare (RO), with 8% violation of thermal limit.

Thus, the Total Transfer Capacity $TTC^{RO \to SCG}$ in case considered was 700 MW. This quantity is 50 MW lower then above mentioned 750 MW, i.e. in case of exchange of 700 MW the security rules are still satisfied. Also, the quantity of ΔEmax was 400 MW (extra increase/decrease of generator's active power over the base case in automatic mode, which is ensured still the safe operation) and the Total Transfer Flow $TTF^{RO \to SCG}$ was 249 MW.

If above mentioned very simple practice (according to the relation TRM [MW] = $100\sqrt{l}$.) is applied in case considered (existence of the single interconnecting line between EPS's RO and SCG - line 400 kV P. De Fier (RO) – Đerdap (SCG)), the value of $TRM^{RO \to SCG}$ would be 100 MW, and the corresponding value of $NTC^{RO \to SCG}$ would be 600 MW.

However, the value of TRM shoud be respected the effects of primary frequency and load-frequency controls, as well as the effects of emergency exchange caused by the unexpected unbalanced situations (big injection losses, e.g. outage of big generators). In case of including this type of disturbances, in considered example of NTC calculation between EPS's RO i SCG, the automatic NTC calculation is stoped for total exchange of 550 MW. In this case, the critical outage was the outage of two generators in TPP Braila (RO) (injection loss of 310 MW and 200 Mvar). The consequences of this outage are

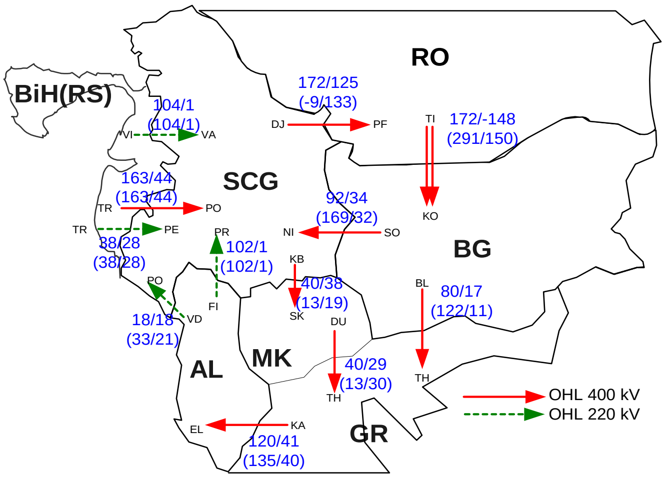

Fig. 2. Active and reactive powers on interconnecting lines of Second UCTE synchronous zone

the violation of voltage limit in several nodes, in part of EPS RO, near to this TPP.

Thus, in this practical example, the value of $NTC^{RO\rightarrow SCG}$ shoud be calculate in following maner:

$$NTC^{RO\rightarrow SCG}=BCE^{RO\rightarrow SCG}+\Delta Emaxl^{RO\rightarrow SCG}-[(\Delta Emaxl^{RO\rightarrow SCG}-\Delta Emaxg^{RO\rightarrow SCG})+TRMo^{RO\rightarrow SCG}]=$$

$$=300+400-[(400-200)+35]=465\text{ MW}$$

where:

$\Delta Emaxl^{RO\rightarrow SCG}$ – maximum value of extra increase/decrease of generator's active power over the base case, during the automatic NTC calculation, which is ensured still the safe operation, for outage element type of disturbances;

$\Delta Emaxg^{RO\rightarrow SCG}$ – maximum value of extra increase/decrease of generator's active power over the base case, during the automatic NTC calculation, which is ensured still the safe operation, for outage generator type of disturbances;

$TRMo^{RO\rightarrow SCG}$ – estimated part of total TRM, which corresponds to the inaccuracies in data and calculation models and/or method (usually, isn't bigger than 5% of computed TTC value).

In practical sense, in this example, $TRM^{RO\rightarrow SCG} = \Delta Emaxl^{RO\rightarrow SCG} - \Delta Emaxg^{RO\rightarrow SCG} + TRMo^{RO\rightarrow SCG} = 235$ MW, because this value "covers" all outages of relevant generators up to the total exchange program RO → SCG 500(300+200) MW, and consequently, the realistic value of $NTC^{RO\rightarrow SCG}$ will be 465 MW.

However, it should be noted that is only one of possible approach, among many others, in contex of attempt to find a more accurate evaulation of TRM. Its is based on calculation of above mentioned values ΔEmaxl and ΔEmaxg, during automatic cross-border transmission capacity assessment.

Naturaly, the problem of more accurate evaluation of TRM needs the further research in thic topic. One possible direction, among other, is necessity of norming the amount of total emergency exchange, caused by the unexpected unbalanced situations (big injection losses, e.g. outage of big generators).

V. Conclusion

A possible way to the evaluation of TRM in automatic cross-border transmission capacity assessment of electric power interconnections has been presented It is based on advanced methodology for NTC calculation, using all its favourable properties, respecting the latest definitions, criterions, standards and practice of European Transmission System Operators. The possibilities of approach presented were demonstrated on example of existing electric power interconnection in Balkans.

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